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A PRELIMINARY RESEARCH ON THE CLIMATIC RECORDS OF LACUSTRINE DEPOSITS OF QINGTU LAKE IN THE LAST 6000 YEARS①

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ABSTRACT: A preliminary study on the advance and the retreat of Qingtu Lake and its climatic records of the Holocene lacustrine deposits has been made through comprehensive analysis. The study shows that the modes characteristics of climatic change in Eastern Hexi Corridor was provided with the corresponding relationship of warm-moist and cold-dry during the scale longer than hundred years. As a result of climatic changes and human activities, Qingtu Lake cycle has undergone four lake-retreated and three lake-advanced stages since 6000 a B. P. Based on the study on lacustrine sedimentary color, grain size, Fe^{3+}/Fe^{2+} and organic matter, the authors put forward that a warm period existed during the phase of 335- 480 A. D. in the studied area. This warm period could be further testified by a lot of evidences obtained from the historical documents and the natural records of Qingtu Lake. In brief, the evolution of lakes in Eastern Hexi Corridor is characterized by sedimentary continuity, fast sedimentary rate and high resolution, it not only indicate the paleoenvironmental and climatic change in Holocene, but also can reflect the intensity of Eastern Asia monsoon.

KEY WORDS: Qingtu Lake, Holocene, lacustrine deposits, climatic records, warm period of 355- 480 A. D.

1 STUDIED REGION AND ANALYSIS METHOD

Located at northwestern margin of Tengger Desert and 70 km northeast of Minqin County in Gansu Province, Qingtu Lake belongs to the Shiyang River Dry Delta, and the altitude is 1292- 1310 m. The region has the character of temperate continental arid desert climate, the annual mean temperature is 7.8 ℃, the annual precipitation is about 110 mm, and the evaporation capacity is above 2600 mm. Presently, Qingtu Lake has already dried completely, and most of it has been cultivated or covered by drifting sand, only leaving some fluvial marshes, including Dongping Lake, Yema Lake, Yelucao Lake, East Xiaochi Lake and West Xiaochi Lake.

Zhiyun village section, selected in the paper, lies in the south of Dongping Lake and about 6 km southwest to Zhongqu County, at 39°3' N and 103°.40' E. The top altitude of the section is about 1309 m, and the thickness of samples is 4.5 m. Fifty-one groups of samples are collected with unequal distance. Generally, samples are collected every 5 cm in limnetic facies, but samples are collected intensively at the horizons varying much in color, grain size and structure, and at the upper un-limnetic facies layer samples are collected every 10 cm. The sample number increases from bottom to top. In the profile, the lithological characters of samples used in ^{14}C dating are all humus muck or peat, and altogether 6 ^{14}C dating data are tested. Geography Department of Lanzhou University

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supplied these data on the routine ^{14}C dating method. Fig. 1 shows that fine linear correlation exists between the horizon depth and ^{14}C dating of Zhiyun village profile. After calculation we get a regression equation $y = 0.05x + 137$, and a correlation coefficient $r = 0.95$. Therefore, using linear interpolation can get age data of other horizons in the profile.

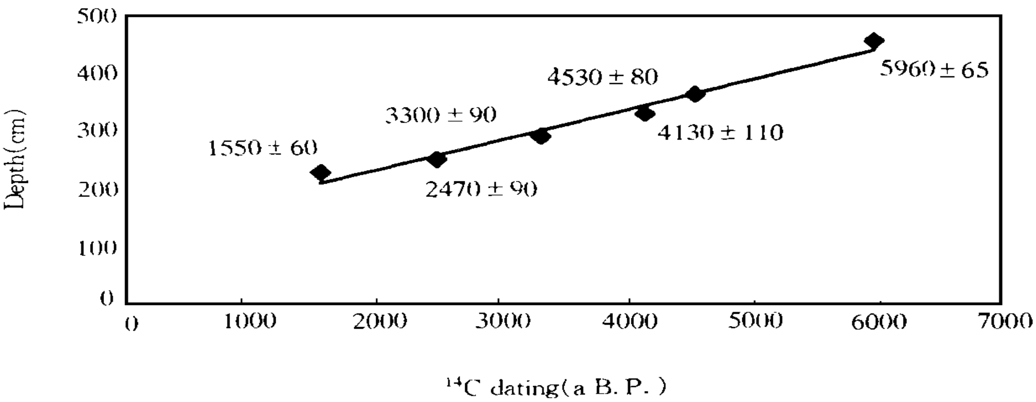

Fig. 1 The relations between profile depth and ^{14}C dating of Zhiyun village profile in Qingtu Lake

Outdoors expedition and indoors analysis prove that, Qingtu Lake was a carbonate-sulfate closed lake before it dried up, and mirabilite appeared in the present East Xiaochi Lake and West Xiaochi Lake with the "bull's-eye" sedimentary model, which is that carbonate precipitates around closed inland salt water basins first, and finally halite and other more soluble salt precipitate at the center or the deepest indentation part of salt lake. The existence of "bull's-eye" salt sediment in Qingtu Lake strongly supports drying history of the lake, but undoubtedly, during the process, the lake area suffered the fluctuation change of enlargement and diminution, so the sediments can be fine climatic records. In order to get climatic substitute indices of lacustrine sediments, we use screen analysis to analyze 51 samples of all, and get 6 classes of grain-size data. The most popular method in chemistry analysis, redox titration is used to test Fe_2O_3 and FeO content of 49 samples, and gas-measuring is taken to meter $CaCO_3$ content of 51 samples. In many ways testing organic matter content of lacustrine sediments, the paper takes externally heating oxidation method, relying on the oxidant — K_2CrO_7 to oxidize organic carbon, re-titrating rest of the oxidant with standard $(NH_4)_2SO_4$ solution, calculating the oxidized organic carbon content based on the consumption of oxidant, then working out organic matter content according to certain equations.

2 CLIMATIC CHANGE REFLECTED BY SEDIMENTARY SEQUENCE AND ADVANCE OR RETREAT OF LAKE

The comprehensive signals, including animal fossil groups, reductive protogenic color, carbonaceous matter and fine laminated structure etc., are taken to develop the concept of rock sequence into the character facies sequence distinguishing the origins of lake. One type is that the section gets coarser from bottom to top, reflecting megaclastic sediments is above the center fine-grain matter in the shore belt and indicating the retreat of lake; the other type is that the section gets coarser from top to bottom, reflecting the change from land facies to lake facies and indicating the lake advance. Sedimentary sequence of lake is the bottom-top integration of lake advance and retreat units in the profile. Zhiyun village section in Qingtu Lake deposits continually, and silt and clay ($> 4\varphi$) content in the lacustrine deposits ranges between 59% – 99% with the clear grain-size change.

Therefore, based on the above-mentioned lacustrine deposit sequence model, the seiche process of Qingtu Lake since the Middle Holocene can be divided into seven phases:

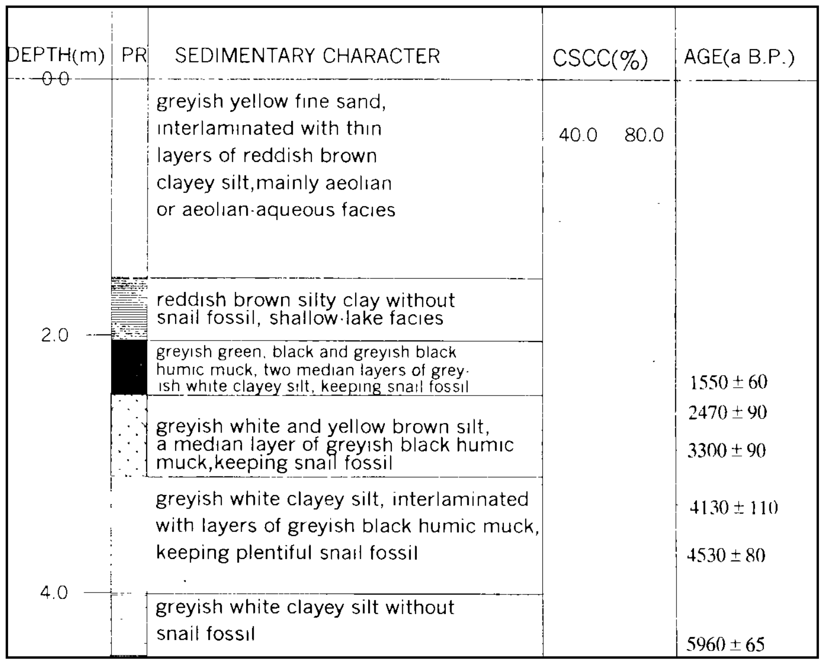

Fig. 2 Sedimentary profile of Zhiyun village in Qingtu Lake

PR means profile, CSCC means the curve of silt and clay content

(1) Lake retreat during 6.0– 5.0 ka B.P.

At 4.0– 4.5 m bottom of the profile, lacustrine deposits appear grayish white without snail fossil. During the phase, the sedimentation rate of lake is 0.63 mm/a, the proportion of silt and clay drops from 83.5% to 76.9%, the grain-size composition grows coarser, so the phase is determined as a process of lake retreat, which reflects decreasing of river water into the lake, climate drying and summer monsoon withdrawing south.

(2) Lake advance during 5.0– 3.8 ka B.P.

At 3.1– 4.0 m from the top, most of lacustrine deposits seem to be grayish white, interlaminated with five layers of grayish black humic muck. Many snail fossils appear in the profile, especially in humic muck. During the period, the sedimentation rate of lake is 0.76 mm/a, the proportion of silt and clay is between 67.5% and 90.8% while the mean is 78.5%. The lake is in the state of advance on the scale of millennium. It can be shown that at that time, river water was plentiful and took lots of sediment into the lake region, reflecting more rainfall in this drainage area and stronger summer monsoon processing north.

(3) Lake retreat during 3.8– 2.5 ka B.P.

At 2.56– 3.1 m from the top, the upper layer (2.56– 2.88m) of lacustrine deposits appears grayish white, the lower layer (2.93– 3.1 m) looks brown yellow or yellow, and the middle is a layer of grayish black humic muck (2.88– 2.93 m) keeping snail fossils. The sedimentation rate of lake is 0.47 mm/a, silt and clay content is 54.7% – 77.1% while the mean is 57.5%, the lowest in the profile, that is, the grain-size is the coarsest. Apparently, the retreat process is relevant to summer monsoon retreating south and climate becoming dry and cold during the Tertiary Neoglaciation.

(4) Lake advance during 2.5– 1.72 ka B.P.

At 2.31– 2.56 m from the top, the upper and lower layers of lacustrine deposits are grayish white and grayish black respectively, and the brown root-holes keeping lots of snail fossil can be found. The sedimentation rate of lake is 0.23 mm/a, the proportion of silt and clay increases from 54.3% to 95.1%. The lake advance should be related to the warm climate during 722 B.C. – 220 A.D.

(5) Lake retreat during 1.72– 1.37 ka B.P.

At 2.15– 2.31 m from the top, lacustrine sediments are grayish white, black and black gray, containing snail fossil. The sedimentation rate of lake is about 0.20 mm/a, and the proportion of silt and clay ranges between 73.8% and 86.9% while the mean is 79.6%, coarser than before. The lake retreat should be the result of climate becoming dry and cold during 220– 580 A.D. However, on the turn of the forth and fifth centuries an event appeared of climate back-warming and rainfall increasing.

(6) Lake advance during 1.37– 1.07 ka B.P.

At about 1.7– 2.1 m from the top, lacustrine deposits mostly appear red brown showing the contemporary shallow warm environment. The sedimentation rate of lake is about 1.33 mm/a, the highest in the profile, indicating much sand supply from river water. Silt and clay content of 98.3% and the fine grain-size composition should belong to the process of lake advance or can be attributable to landuse.

(7) Lake retreat after 1.07 ka B.P.

Since the Song Dynasty and Yuan Dynasty, the global climate enters Modern Little Ice Age, and climate in the region becomes drier and colder. Until the forepart of the Qing Dynasty, Qingtu Lake weathered and decomposed, dried up to land gradually and becoming aeolian-aqueous facies or aeolian sand accumulation.

3 CLIMATIC CHANGE REFLECTED BY CHEMICAL COMPOSITION OF GYTTJA

3.1 Fe^{3+}/Fe^{2+} Ratio

Research has shown that mineralization degree of hematite in sediments is relevant to the contemporary sedimentary environment, especially to the surface temperature (Zhu, 1994). Fig. 3a is the variation curve of Fe^{3+}/Fe^{2+} ratio in Zhiyun village section, from which it can be observed that on the scale of millennium, the Second New Ice Age, the Tertiary New Ice Age and the Modern Little Ice Age all respond to low value. In the whole profile, Fe^{3+}/Fe^{2+} ratio ranges between 0.41– 3.83. The mean at 1.5 – 4.5m from the top is 1.45. The lowest is 0.41 appearing at 3.5m from the top (equal to 4.4 ka B.P.), and whether this represents an event of drop in temperature needs further verifying. The second lowest, 0.52, appears at 4.0 m from the top (equal to 5.3 ka B.P.), and many research institutions have disclosed that the event of drop in temperature has global significance. The highest 3.83 appears at 2.15 m from the top (equal to 670 A.D.), compatible with the warm period during 581 A.D. – 907 A.D. observed by Zhu Kezhen (1973), the second highest 3.56 appears at 2.46 m (equal to 2.4 ka B.P.), which happens to respond to the second warm period put forward by Zhu Kezhen, and the paper also finds that the higher Fe^{3+}/Fe^{2+} ratio responds to climatic warm periods. Clearly, the Fe^{3+}/Fe^{2+} ratio of profile well reflects cold/warm climatic change during the median and later periods of the Holocene.

3.2 Organic Matter Content

Organic matter in lake deposits develops from complex origins. Kelts (1992) pointed out that developing turf or high organic matter content was the sedimentary record of climate becoming better. In the region, water is the principal factor of natural environment, so higher organic matter content in lacustrine sediments should indicate humid climate while lower content indicates comparatively arid climate. Fig. 3b shows the variation curve of organic matter content in Zhiyun village profile in Qingtu Lake, from which we can observe that in the region, since the Miocene epoch and the Holocene there are at least five events of precipitation increase on the scale of about 100 a. These events occurred in 4.53 ka B.P., 4.13 ka B.P., 3.30 ka B.P., 2.47 ka B.P. and before or after 400 A.D. Furthermore, these events are all characteristics of warmth and humidity.

3.3 Cl^- Content

In the closed inland rivers and lake of arid regions, Cl^- content in deposits not only reflects lake water salinity during deposit, but also indicates climatic change indirectly. To say specifically, the layer segment keeping higher Cl^- content reflects more arid climate while the layer segment keeping lower Cl^- content reflects wetter climate. Fig. 3c shows the variation curve of Cl^- content in Zhiyun village profile, Cl^- content in lacustrine deposits at 1.5– 4.5 m from the top ranges between 0.0078% – 0.0175%, the mean is 0.0124%, and the lowest appears at 2.25– 2.29 m (equal to about 400 A.D.), which strongly supports our conclusion of warm and wet climate during the forth and fifth centuries.

3.4 $CaCO_3$ Content

The variation of $CaCO_3$ content in sediments depends on various factors, and the solubility of $CaCO_3$ is related to temperature, pH value and CO_2 partial pressure. In lacustrine deposits, carbonate deposits represented by calcite, is the early phase of lacustrine salt depositing and can reflect climatic change in a sense. Fig. 3d shows the variation curve of $CaCO_3$ content in Zhiyun village profile, the fluctuation of which is basically reverse to the curve of organic matter content and well reflects the change of precipitation conditions in the basin lake. Based on the statistics of 30 samples at 2.25– 4.5 m from the top, it can be found that $CaCO_3$ content is negatively correlated with organic matter content, and the correlation coefficient $r = -0.67$. Therefore, the higher $CaCO_3$ content is connected with higher evaporation capacity or less water amount of the Shiyang River, that is to say, it responds to dry and cold climatic period. By contrast, the lower $CaCO_3$ content responds to warm and wet climate.

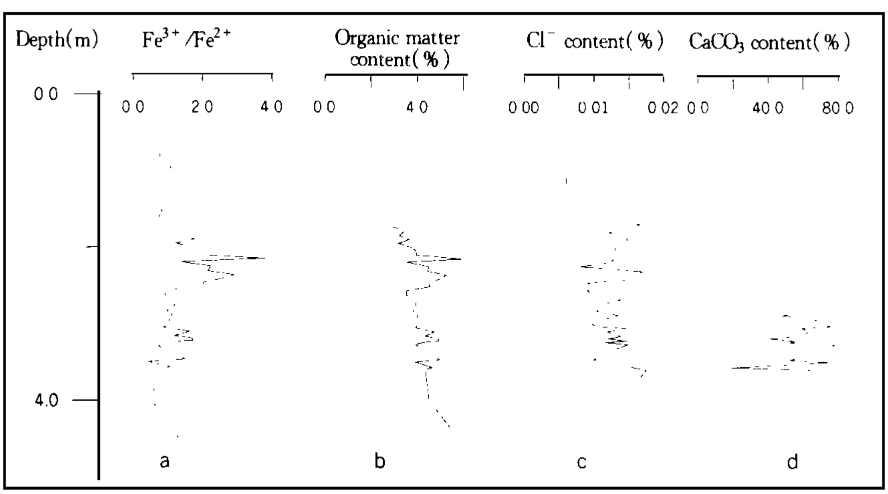

Fig. 3 The variation curve of climate proxy in the profile of Zhiyun village

4 SOME DISCUSSIONS ABOUT THE CLIMATE BACK-WARMING DURING THE FORTH AND FIFTH CENTURIES

Zhu Kezhen (1973) thought that the period during 220– 580 A.D. was a consistently cold phase, and evaluated that the temperature in the phase was 1 – 2℃ lower than now. In the present opinions, the conclusion is incomplete. For example, at 2.25– 2.29 m from the top in Zhiyun village profile is a black humic muck sod (^{14}C dating is 1550 ±60 a B. P.), Fe^{3+}/Fe^{2+} ratio curve of which is on-peak, organic matter content of which is the highest in the profile, 3.55%, and undoubtedly, all these are powerful evidences of the warm and wet climate during the forth and fifth centuries. Research by Zheng Xiyu *et al*. (1992) also proves that, in the arid inland lake of monsoon marginal regions, black and grayish black muck sediments keeping ample organic matter usually indicate the comparatively warm and wet climate (Zheng *et al*., 1992). About the climate back-warming event, we also can be supported by the history documents of Hexi Corridor.

Table 1 shows the climatic disasters in Hexi Corridor between 225 A.D. – 580 A.D., and the time scan of data is 296 years from 225 A.D. to 531 A.D., in which climatic disaster data for 32 years are collected and amount to 36 items. It can be found that no frost and snow injuries appeared in Hexi Corridor during 335– 478 A.D., when planting mulberries and raising silkworms was very prevalent there, reflecting comparatively appropriate climatic conditions. The most frequent period of frost and snow injuries appearing is the first ten years during the sixth century, which reach 4 times, and the abruptly changing character of climate cooling can be found. According to the history documents in "the Book of Jin Dynasty History" and "Commentary and Subcommentary to Water Classics", on the turn of the forth and fifth centuries, water conditions in Hexi Corridor were better than now.

It should be pointed out that the climate back-warming during the forth and fifth centuries, recorded in Zhiyun village profile in Qingtu Lake, isn't an isolated local event, but has a general sense. The reconstruction of the paleowater temperature in Qinghai Lake by Zhang Pengxi *et al*. (1994) shows that, at the 4.75 m depth of sampling (^{14}C dating is 1518 a B.P.), the paleowater temperature is 14.2℃ (Zhang *et al*., 1994), not only higher than that during the back and fore time intervals, but also higher than that now. By analyzing the records of drought and flood, Zhang Peiyuan *et al*. (1994) think it is a warm climate period during 360– 490 A.D. Relying on the distribution situation of elephant groups and peacocks described by "History of Shixing" (380– 435 A.D.) and "A Survey of Nanyue" (420– 479 A.D.), Li Pingri *et al*. also draw the conclusion that the contemporary climate is warmer and hotter than now. In short, the climate back-warming phenomenon during the forth and fifth centuries put forward in the paper, may be an oscillation on the scale of 100 years, and has an important sense in acknowledging periods of climatic change from 225 A.D. to 580 A.D., which will be further studied in other papers.

REFERENCES

Kelts K., 1992. Lacustrine sediments — the information base of past changes. *Quaternary Sciences*, 2: 138– 143. (in Chinese)

Li Pingri, Tan Huizhong, Hou Deping, 1997. Climate and environmental changes along the South China coast over the past 2000 years. *Quaternary Sciences*, 1: 86– 94. (in Chinese)

Zhang Pengxi, Zhang Baozhen, Qian Guimin *et al*., 1994. The study of paleoclimate parameter of Qinghai Lake since Holocene. *Quaternary Sciences*, 3: 225– 238. (in Chinese)

Zhang Piguan, Wang Zheng, Liu Xiaolei, 1994. The modes of climatic changes over the last 2000 years in China. *Science in China (Series B)*, 24(9): 998– 1008. (in Chinese)

Zheng Xiyu, Zhang Minggang, Dong Jihe *et al*., 1992. *Salt Lake of Inner Mongolia*. Beijing: Science Press, 195– 202. (in Chinese)

Zhu Cheng, 1994. The application of Fe^{3+}/Fe^{2+} in probing into the Quaternary paleotemperatures of Lushan Mountain. *Geological Review*, 40(3): 216– 220. (in Chinese)

Zhu Kezhen, 1973. A preliminary study on the climate fluctuations during the last 5000 years in China. *Scientia Sinica*, 2: 168– 189. (in Chinese)

Table 1 The climatic disasters in Hexi Corridor from 225 A. D. to 580 A. D.

Disaster type	A. D.	Disaster situation	Sources
Drought damage and plague of locusts	270	In May, drought and famine in Yong, Liang and Qin prefectures	"The Book of Jin Dynasty History· Basic Annals"
	301	In July, plague of locusts in Xianmei County and plague of snout moth's larva in Guzang County	"The Book of Jin Dynasty· A Survey of Wuxing"
	365	Drought in Liang Prefecture from spring to summer	"The History of Wuliang" (1749)
	369	Drought in Liang prefecture from spring to summer	"The Book of Jin Dynasty History· A Survey of Wuxing"
	387	In winter, serious famine in Liang Prefecture	"A Survey of Wuliang"
	399	Drought and famine in Guzang County	"The Book of Jin Dynasty History · A Biography of Lulong"
	401	Drought and famine in Guzang County	"The History of Hexi" (1959)
	402	Famine in Guzang County	"The Book of Jin Dynasty History · A Biography of Tufaliluhu"
	405	In spring, drought in Zhangye	"The Book of Jin Dynasty History · A Biography of Tufaliluhu"
	451	In July, plague of locusts in Dunhuang Town	"The Book of Wei Dynasty History · A Survey of Lingzheng"
	480	In July, plague of locusts in Dunhuang Town	"The Book of Wei Dynasty History· A Survey of Lingzheng"
	496	In December, drought in northwestern prefectures	"The Book of Wei Dynasty History · A Survey of Lingzheng"
	504	In August, plague of locusts in Liang Prefecture	"The Book of Wei Dynasty History· A Survey of Lingzheng"
	507	In August, plague of locusts in Liang Prefecture	"A New General Survey of the Whole Gansu Province"
	508	In June, plague of locusts in Liang Prefecture	"A New General Survey of the Whole Gansu Province"
	510	In summer, plague of locusts in Liang Prefecture	"The Book of Wei Dynasty History · A Survey of Lingzheng"
	531	In May, drought in western regions	"The Book of Wei Dynasty History · Basic Annals"
Frost and snow damage	284	Rain-storm in five prefectures of Nan'an in autumn, frost damage in Xiping Prefecture	"The Book of Jin Dynasty History · A Survey of Wuxing"
	354	In May, snow and frost damage in Liang prefecture	"The Book of Jin Dynasty History· A Survey of Wuxing"
	479	In July, frost damage in Yong and Su prefectures, Fuhan, Dunhuang and Qiuchi countries	"The Book of Wei Dynasty History · A Survey of Lingzheng"
	503	Frost damage in Dunhuang Town	"The Book of Wei Dynasty History · A Survey of Lingzheng"
	505	In July, frost damage in Dunhuang	"The Book of Wei Dynasty History · A Survey of Lingzheng"
	507	In April, frost damage in Dunhuang Town	"The Book of Wei Dynasty History · A Survey of Lingzheng"
	509	In April, frost damage in Dunhuang	"The Manuscript of the General Survey in Gansu Province"
Wind damage	249	In January, northwestern wind damage and dust-storm	"A New General Survey of the Whole Gansu Province"
	300	Northwestern wind damage until June	"A New General Survey of Gansu Province"
	304	In January, northwestern wind damage	"A New General Survey of Gansu Province"
	351	In March, wind damage and dust-storm in Liang Prefecture	"The Book of Jin Dynasty History · A Survey of Wuxing"
	393	Wind damage in Zhangye Prefecture	"A Survey of Ganzhoufu"
	405	Northwestern wind damage and dust-storm in western prefectures	"The Book of Jin Dynasty History · A Biography of Juqumengxun"
	503	Wind damage and dust-storm	"The Book of Wei Dynasty History · A Survey of Lingzheng"
Flood damage	235	Flood at the Liu Valley mouth in Zhangye	"A New General Survey of Gansu Province"
	284	In September, heavy rain, flood and snow-storm in five prefectures of Nan'an, heavy rain and flood in nine counties of Xiping Prefecture	"The Book of Jin Dynasty History · A Survey of Wuxing"
	320	Flood damage in Liang Prefecture	"A Survey of Wuliang"

Notes: Months in the table are all calculated according to lunar calendar; place names in the table all respond to the contemporary places.